



**A Review of Manned Thermal Garment Diving Studies
With Lessons Learned for the SDV Operator
and Combat Swimmer**

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The experiments reported herein were conducted according to the principles set forth in the current edition of the "Guide for the Care and Use of Laboratory Animals," Institute of Laboratory Animal Resources, National Research Council.

This technical report has been reviewed by the NMRI scientific and public affairs staff and is approved for publication. It is releasable to the National Technical Information Service where it will be available to the general public, including foreign nations.

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DEDICATION

This review is dedicated to every Navy frogman who has ever been cold and wet .

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BACKGROUND

Special Operations SEAL (Sea, Air, and Land) Delivery Vehicle (SDV) operators and combat swimmers are often required to conduct their missions in a cold-water environment. Successful completion of the mission and the safety of the diver are contingent upon good dive training, sound mission planning and preparation, and adequate thermal protection.

A variety of manned biomedical thermal research studies have been conducted in the past and reported on individually. Some of these studies' findings may be able to significantly enhance mission planning and preparation for combat swimmers.

GOALS

The goals of this report are to (1) review the most relevant thermal studies to date as they apply to SDV and combat-swimmer diving and (2) to make clear recommendations based upon these studies, in order to enhance combat swimmer mission planning and preparation.

REVIEW OF DIVING THERMAL STUDIES

This report will review 11 of the most relevant manned thermal studies applicable to SDV and combat-swimmer diving. These studies collectively represent over 300 manned experimental dives, using a wide variety of thermal protective garments, water temperatures, activity levels, and exposure times.

Outcome for the majority of the studies focused on the measurements of core (rectal) temperatures and, occasionally skin temperatures during the exposure. The other major outcome measured was whether or not the diver was able to complete the cold-water exposure.

It should be noted that there was very limited (if any) measurement of Special Operations and/or combat swimmer mission-related performance in any of these studies. Therefore, the adequacy of the thermal protection was determined by the ability of the diver to complete his dive and maintain his core body temperature above the upper limit of mild hypothermia ($>35^{\circ}\text{C}$ or $>95^{\circ}\text{F}$). While this information is very useful, it must be remembered that the combat swimmer's ability to complete a cold water exposure and his ability to complete the exposure *and* "fight", may be two very different answers.

References will be made frequently to the Appendices (A - M) of this report. These appendices are summarized as follows:

- Appendix A - lists some general information on exercise/work and concerning the conversion between degrees centigrade ($^{\circ}\text{C}$) and degrees Fahrenheit ($^{\circ}\text{F}$).
- Appendix B - lists some generally accepted correlations between body core temperatures and degrees of hypothermia.

- Appendices C-M - represent 11 of the most applicable manned thermal studies to SDV and combat-swimmer diving. Each appendix includes a summary of the study and its results, as well as a brief comment about the most important lessons learned from each study.

The 11 studies reviewed in this report (see appendices C-M) will be commented on, based upon the following three broad categories:

1. Wet-Suit Studies
2. Dry-Suit Studies
3. Other Special Operations Cold-Water Diving-Related Studies

WET-SUIT STUDIES

This review will look at 5 studies of wet suit divers, which represent a total of 111 man-dives with 39 of these in ≤ 50 °F water. All were done at shallow depths (with a greatest depth of 15 feet of seawater (fsw)) and most of these dives were done by Underwater Demolition Team (UDT)/SEALs or Basic Underwater Demolition (BUD)/S trainees. The activity levels varied between rest and heavy work.

Table 1 is a summary of the wet suit studies. Appendices C, D, E, G, and K give more detailed descriptions of each individual study.

TABLE 1. SUMMARY OF WET-SUIT STUDIES

Study Append) Auth	Diver's Dress	Water Temp (°F)	Diver's Activity/Work	Depth (FSW)	Duration (hours)	Man-Dives Completed/Attempted	Avg Total change in core Temp (°C)	Aborted Dive Duration (hours)	Reason for Abort	# of Divers w/ Hypothermic (<35°C) Core Temps
C) Vaughan (1)	1/4" Wet Suit (WS)	43	Rest	15	4	12/12	1.2	-----	----	0
"	"	43	Rest	15	6	8/8	1.2	----	----	0
D) Lippitt & Bond (2)	1/4" WS	40	Rest	6	6	1/2	Not Recorded (NR)	3.5	Numb Legs	0
"	"	40	Light	6	6	0/2	NR	3.5 & 4	Cold	0
"	"	40	Moderate	6	6	1/2	NR	4	Ear Problem	0
"	"	60	Rest	6	6	2/2	NR	-----	----	0
"	"	60	Light	6	6	2/2	NR	-----	----	0
"	"	60	Moderate	6	6	2/2	NR	-----	----	0
"	"	80	Rest	6	6	2/2	NR	-----	----	0
"	"	80	Light	6	6	2/2	NR	-----	----	0
"	"	80	Moderate	6	6	1/2	NR	3	Equipment Problems	0
F) Lippitt & Bond (3)	1/4" WS	45	Light	6	6	2/2	0.78	----	----	0
"	"	45	Moderate	6	6	1/2	1.04	4.5	GI Upset	0
"	"	50	Light	6	6	1/2	0.56	4.3	GI Upset	0
"	"	50	Moderate	6	6	1/2	1.17	3.5	Suit Collar Too Tight	0
G) Thalmann (4)	~1/3" WS	35-40	Rest	~10	1 (Mean Exposure Time of 69 Minutes)	5/5	1	----	----	0
K) Prusaczyk (5)	3/8" WS	57	Moderate - Heavy	Surface	4	36/36	0.6	----	----	1, may be secondary to afterdrop
"	3/8" WS Top Only	62	Moderate - Heavy	Surface	4	24/24	1.4	----	----	3, may be secondary to afterdrop
						Total = 111 Man Dives				

Some important observations can be made from this table, as follows:

- Below a water temperature of 40 °F, only 5 experimental dives using wet suits were done with an average exposure time of 69 min. None of the divers reached a core temperature of <35 °C. (see Appendix G)
- In the 40-50 °F water temperature range, 34 man-dives were completed in wet suits. All of these dives were at least 3.5 h long, with no diver reaching a core temperature of <35 °C. Perhaps the most severe exposures were the 8 man-dives for 6 h in wet suits in 43 °F water at 15 fsw, which are listed in Appendix C. Also of note is that the length of time the diver lasted in the water (3.5-6 h) seemed more dependent on the individual diver, rather than his activity level. This emphasizes the effect individual variation has on cold-water tolerance.
- Above a water temperature of 50 °F, all of the dives went to their planned completion. Six dives in wet suits in 60 °F water went to their planned completion time of 6 h, with no diver reaching a core temperature of <35 °C.

Thirty-six surface swims in wet suits in 57 °F water and 24 surface swims in wet suit tops in 62 °F water all went to their planned completion at approximately 4 h.

However, 4 of these 60 divers were noted to have core temperatures of <35 °C when measured approximately 13 min after their swim. This may be due to the "afterdrop phenomena" and will be discussed in detail later in this report.

Very few experimental wet suit dives have been done in water below 40 °F, but certainly one can expect limited duration dives. In 40-50 °F water, 3.5-hour dives seem fairly reproducible, but clearly there is a limit that is most dependent on individual variation. When it comes to planning mission durations, the difference between 40 and 50 °F water is probably quite great. Lastly, water temperature above 50 °F allows 6-hour dives to be reliably completed in wet suits.

Again, it should be noted that there was very limited (if any) measurement of Special Operations and/or combat-swimmer mission-related performance in any of these studies. Therefore, the dive times listed at the various water temperatures while wearing wet suits are based upon the diver maintaining his core body temperature above the upper limit of mild hypothermia ($>35^{\circ}\text{C}$ or $>95^{\circ}\text{F}$) and his ability to complete the dive. While this information is very useful, it must be remembered that the combat swimmer's ability to perform mission-essential tasks may be impaired, even though his core temperature is $>35^{\circ}\text{C}$. In fact, most of these studies note the diver's impaired status in their reports, but do not quantify these observations with objective measures of performance. Also, most of these dives were done at ≤ 6 fsw. Therefore, the depth-dependent degradation of wet suit insulation must be factored in as well. (See the Collective Lessons Learned/Recommendations section of this report for comments concerning the insulative value of a wet suit with changes in depth.)

Lastly, there were no dives aborted due to a suit malfunction or "leak." This may seem obvious with a wet suit, but should be kept in mind as one compares these dives with the dry-suit dives.

DRY-SUIT STUDIES

This review will look at 4 studies of dry-suit divers, which represent a total of 144 man-dives. One-hundred and forty of these were done in $\leq 40^{\circ}\text{F}$ water. Most were done at shallow depths (≤ 20 fsw) and were done by U.S. Navy Divers. Only a small percentage were done by UDT/SEALs. The activity levels varied between rest and heavy work.

Table 2 is a summary of the dry suit studies. Appendices E, F, I, and J give more detailed descriptions of each individual study.

Some important observations can be made from this table:

- Most of the dry suit dives conducted in 40°F water over a range of activity levels were complete, 6-hour dives, with the divers' core body temperatures protected ($>35^{\circ}\text{C}$). Only 5 of the 140 (3.5%) man-dives in $<40^{\circ}\text{F}$ water reached a core temperature of 35°C .
- It should be noted that the dry suit garment ensembles tested in these 4 studies used various undergarment configurations, but each undergarment required approximately 70-90 lb of weight to achieve negative buoyancy. As the trapped air in each undergarment provides the majority of insulation, this amount of

weight translates into a high quantity of trapped air/insulation, but a bulky garment. This bulkiness may not always be affordable, given the SDV or combat swimmer's mission requirements.

frequently used underwater "tool", lowered hand temperatures (and therefore hand manual dexterity and strength) become the most common complaint and the most common mission-limiting factor in dry suit diving.

Lastly, despite the "ideal" conditions of experimental diving (minimal sharp edges, new suits being tested, suits donned in optimal conditions, etc.) and despite the training usually involved in experimental diving, dry suits still occasionally leak. Therefore, the SDV diver or combat swimmer must still weigh the improved thermal benefits of a non-leaking dry suit against the "colder" yet more reliable wet suit.

OTHER SPECIAL OPERATIONS COLD-WATER DIVING-RELATED STUDIES

Appendix L summarizes a study entitled "Effects of Serial Wet-Dry-Wet Exposure: Thermal Balance, Physical Activity, and Cognitive Performance" (10). This study involved a 2.5-hour dive in 5 °C (~ 41 °F) water (simulating a water-borne insertion), followed by a 2-hour dry cold exposure at 5 °C air temperature (simulating a land phase), and lastly another 2.5-hour dive in 5 °C water (simulating extraction). This study was patterned after a February 1987 Naval Special Warfare (NSW) training exercise that involved a serial wet-dry-wet exposure in similar water and air temps and of similar duration. The observation was made during that exercise that "vigilance... appeared to be reduced" and that "procedural errors were made when the divers prepared to reenter the water" (10). Therefore, the question of what role hypothermia and/or fatigue played in these decrements in performance was asked.

TABLE 2. SUMMARY OF DRY-SUIT DIVES

Study Append Auth	Diver's Dress	Water Temp (°F)	Diver's Activity	Depth (FSW)	Duration (hours)	Man-Dives Completed/Attempted	Avg Total change in Core Temp (°C)	Aborted Dive Duration (hours)	Reason for Abort	# of Divers w/ Hypothermic (<35°C) Core Temps
E) Lippitt & Bond (3)	DrySuit (DS) w/ "Arctic Underwear" and Urine Collection Device (UCD)	35	Rest	6	6	¾	0.87	3	GI Upset	0
"	"	35	Light	6	6	4/4	0.83	---	---	0
"	"	35	Moderate	6	6	2/2	0.87	---	---	0
"	"	40	Light	6	6	2/2	0.60	---	---	0
"	"	45	Light	6	6	2/2	0.68	---	---	0
"	"	50	Light	6	6	2/2	0.34	---	---	0
F) Piantadosi (6)	DS w/M-400 Thinsulate	40	Rest	10	2.5	3/4	0.5	1	Suit Flooded	0
"	"	40	Moderate	10	2.5	4/4	0.1	---	---	0
"	"	40	Heavy	10	2.5	4/4	0.6	---	---	0
"	"	35	Rest	70	3.0	6/8	0.7	2 & 2.5	Shivering & "Technical Problems" Respectively	0
"	"	35	Moderate	70	3.0	7/8	0.1	0.75	Suit Flooded	0
D) Doubt (7), Weinberg (8)	DS w/ M-600 Thinsulate & UCD	40	Very Light to Light	20	6	27/63	1.9 (± 0.6)	Variable	5 Dives-Low Rectal Temps 14 Dives-Low Finger Temps 7 Dives-Subject Requests (5 GI Upset & 2 Headaches) 10 Dives-Equip. Malfunctions Including Suit Leaks	5
J) Wienberg (9)	DS w/ M-400 to M- 800 Thinsulate & UCD And Actively Heated Gloves	37	Rest	6	8	29/37	1.2 (± 0.3)	Variable	5 Dives-Equip. Malfunctions Including Suit Leaks 3 Dives-Subject Requests (1 Cold Feet, 1 Cold Hands, & 1 Headache)	0
Total = 144 - Man - Dives										

- Ten out of the 140 (7.1%) dry suit dives abruptly ended due to a significant suit leak. These 10 suit leaks were "true" leaks that could have occurred in the field. In other words, they did not include the other "equipment malfunctions" that may end *experimental* dives prematurely (i.e., leaks around special suit penetrators used to monitor body temperatures, heart rates, rhythm, etc.)
- In each of the 4 studies of dry suit divers, the complaint of cold hands and feet seemed to be the most common mission-limiting factor, which makes it *the* weak link in the generic dry suit garment. It should be noted that in most of these studies hand position was not tightly controlled. Therefore, if divers were allowed to keep their hands above the collapse plane (usually at chest level), then their gloves would remain inflated and would significantly improve their thermal protection. This again is not often possible for an SDV operator or combat swimmer, who must keep his hands below chest level to operate SDV controls or carry an attack board. Therefore, an even greater problem with the thermal protection of the hands in the real operational environment can be anticipated.

In summary of the dry suit dives, **passive insulation alone** (although bulky) appears to sufficiently protect the core temperature in 6-hour dives done in water <40 °F over a range of activity levels. Passive insulation alone **does not** appear sufficient to maintain hand and foot temperatures at a point desirable for Special Operations Forces (SOF) missions in these same conditions. Because hands are the most

The answers the study provides serve to **objectively quantify** some of the physiological measures probably found on many similar NSW missions/exercises. This study found that even very light exercise (walking on a treadmill at a slow pace), significantly improved both the core *and* hand/extremity skin temperatures. In summary, performance decrements were seen in this study and were probably due to multiple factors including cold stress, dehydration, and generalized fatigue.

Appendix M summarizes a study entitled "Skin Blood Flow During Cold-Water Acclimation" (11). This study tested the hypothesis that cold acclimation can be induced in a laboratory setting and observed the time course of that acclimation. It found that skin blood flow was maximally decreased after 2 weeks of daily exposures for 1.5 h while wearing shorts in 64 °F water. This information is most useful for an SDV operator or combat swimmer who is attempting to cold-water acclimate before a mission/exercise.

COLLECTIVE LESSONS LEARNED / RECOMMENDATIONS

The following recommendations based upon the findings of the studies reviewed in this report can be made for all divers anticipating cold-water exposures. The references for these statements/recommendations are the Appendices cited at the end of each statement.

1. Select Your Divers Carefully, Based Upon Past Performances In Cold Water

- Individual differences in handling thermal exposures are great. Therefore, while two people may have the same percentage body fat, may wear an identical thermal protective garment ensemble, and may perform the same workload, their core temperature changes and ability to endure a cold exposure may be very different. (See Appendix C for examples and details.)

2. Plan To Acclimate Your Divers

- Daily 1.5-hour swims/exposures for 2 weeks duration, wearing shorts only, in 18 °C (65 °F) water will produce significant acclimation to the cold. This acclimation benefit will last for up to another 2 weeks. Daily exposures for 4- and 6-week durations produced no extra acclimation benefit. (See Appendix M for examples and details).

3. Plan For Steady Moderate Work - Avoid Overexertion

- "Moderate" work best preserves core body temperatures, while "heavy" work is associated with greater core temperature drops given the same conditions. Therefore, while combat swimming or working underwater, do so at a steady moderate pace and avoid overexertion. (See Appendix F for examples and details.)

4. Light Exercise Is Beneficial

- The beneficial effect on thermal balance of even light exercise should not be underestimated. If the situation permits a diver to swim/exercise lightly or even walk in place during a land phase, then this should be exploited. This beneficial effect is limited to the period of the actual exercise and for a period of time afterward. After that, the diver's thermal status may return to a point as if he had not exercised. (See Appendices I and L for examples and details.)

5. Cover Exercising Muscle Groups

- The greatest heat loss for the exercising diver is through the exercising muscle groups. The swimming diver, for example, should insure that his thighs and calves are adequately insulated. In other words, swimming with a wet suit top only in cold water (<65 °F) *may* put the exercising diver at risk for hypothermia. Farmer Johns with a cheater top and hood (leaving the arms exposed) *may* provide a better option. (See Appendix K for examples and details.)

6. Wet Suits vs. Dry Suits

- In August 1989, the Navy Experimental Diving Unit (NEDU) published "Insulation, Compressibility and Absorbency of Dry Suit Undergarments" (12). A calibrated thermal conductivity instrument called a "Rapid-k" was used to measure the insulation of various dry suit undergarment materials. Based upon

the undergarment's water weight gain and insulation's measurements dry and wet, **the most superior undergarments were M-600 weight Thinsulate and Flectalon**. One interesting table from that report listed the clo value (a unit of thermal insulation) of the garments tested both dry and wet, as summarized below:

Table 3. Insulative Value of Dry suit Undergarments Dry vs. Wet (Summary of NEDU Report #10-89 Table 6)(12)		
<u>Garment</u>	<u>Clo Dry (mean \pm SD)</u>	<u>Clo Wet* (mean \pm SD)</u>
M-600 Thinsulate	1.065 \pm .100	.182 \pm .017
Flectalon	1.086 \pm .101	.192 \pm .073
Wet suit**	not applicable	~ 0.7 - 0.8

*Note: "Wet" in this study meant soaked in water and then hung until all of the visible dripping ceased.

**Note: The wet suit was not tested in this study, but is generally accepted to have an approximate clo value of ~ 0.8 for the 1/4" Farmer John with 1/8" Vest w/ hood, 1/4" Jacket w/ hood and 3/16" Mittens & boots while on the surface.

The following can be concluded from the above table:

1. Both the Thinsulate and Flectalon undergarments when wet retain only ~17% of their insulative value and are significantly less insulating than a wet suit. Therefore, a wetsuit provides significantly more thermal protection than a "wet" dry suit.
2. Dry Thinsulate and Flectalon are more insulating than the wet suit on the surface. This difference is even greater as the depth of the dive increases,

because these dry suit undergarments maintain their degree of thermal insulation, while the wet suit's insulative value is degraded.

A report by Naval Coastal Systems Laboratory (NCSL) in 1978 entitled "Thermal Considerations in the Design of Diver's Suits" (13) suggests that wet suit insulation may be degraded by depth as follows:

<i>Table 4. Insulative Value of a Wet Suit with changes in Depth (Summary of NCSL TM 218-78 Figure 7) (13)</i>	
<u>Depth (fsw)</u>	<u>% of insulative value on the surface</u>
20 fsw	80%
40 fsw	65%
60 fsw	50%
100 fsw	30%

Therefore, once 100 fsw is reached the wet suit offers only ~30% of its insulation, as compared to the wet suit on the surface. Thus, for deep (>100 fsw) cold-water diving for the free-swimming diver, the dry suit becomes the only option. However, for the shallow (<100 fsw) cold-water free-swimming diver, the debate between the merits of the wet suit and the dry suit can only be solved by the divers themselves, who best know their own mission requirements and operational limitations.

One scheme outlined by the Operations Officer of SDV Team 1 in 1991 at the NSW Thermal Workshop (14) (held at the Naval Medical Research Institute (NMRI)) listed the following recommended thermal protection for a given water temperature:

Table 5. SDV Team One's Recommended Thermal Protection for Various water temperatures.(14)	
<u>Water Temp (°F)</u>	<u>Recommended Thermal Garment</u>
> 54 °F	Phase I / Phase II Wet suit
52 - 54 °F	Dry suit with C-400 or C-200 thinsulate
48 - 52 °F	Dry suit with C-600 or C-400 thinsulate
42 - 48 °F	Dry suit with C-600 thinsulate

With this thermal protection scheme, the operators felt they could realistically conduct 6- to 12-hour missions. In general, this scheme is well supported by the manned thermal dive studies reviewed in this report.

7. Plan On Wet Suits Until Below 50 °F Water Temperature For The Resting Diver

- Although the reviewed wet suit dives reflect very few experimental dives done in water below 40 °F, limited duration dives can be expected. Dives done in 40-50 °F water for 3.5 h are consistently reproducible, but clearly there is a limit that is most dependent on individual variation. Lastly, water temperature above 50 °F allows dives of 6 h to be reliably completed in wet suits. Again, planners should realize that performance will be degraded after a significant cold exposure (i.e., 6 h in wet suits in 50 °F water), although the extent of that degradation in performance is not well known. The light to moderately exercising diver may expect longer duration dives. (See the Wet Suit section of this report for examples and details.)

8. Dry Suit Weaknesses Include Hand Temperatures And Suit Leaks

- In summary, of the dry suit dives reviewed in this report **passive insulation alone** (although bulky) appears sufficient to protect the core temperature in 6-hour dives in <40 °F water over a range of activity levels. Passive insulation alone **does not** sufficiently maintain hand and foot temperatures under these same conditions. Therefore, hand temperatures represent the mission-limiting factor in dry suit diving.

Lastly, despite good conditions and training, dry suits will occasionally leak. Therefore, the SDV diver or combat swimmer must still weigh the improved thermal benefits of a non-leaking dry suit against the "colder" yet more reliable wet suit. (See the Dry Suit section of this report for examples and details.)

9. Plan To Rehydrate Immediately Upon Transitioning To Land

- A single dive of 3-6 h in cold water can result in a 2- to 8-pound weight loss through urination, which is equivalent to losing 1-3 quarts of fluid. This fluid should be replaced as soon as possible once on land (underwater rehydration is only minimally successful, as most of the fluid ingested is incorrectly interpreted by the heart as an increase in overall blood volume and subsequently urinated away), because even mild dehydration adversely affects performance. See (Appendix L for examples and details.)

10. Be Aware Of The "Afterdrop" Effect On Core Temperatures

- Body core afterdrop is defined as the continual decline in body core temperature during the initial rewarming period. The afterdrop effect is due to the return of cooled blood from the extremities to the central or core circulation as the diver begins to rewarm after a cold exposure. The afterdrop effect is a normal and predictable physiological mechanism, which must be kept in mind by SDV operators and combat swimmers who plan a land phase to their mission. During their initial transition to the typically warmer land phase, the core temperature will reach its lowest point, and the diver may be most vulnerable to the effects of even mild hypothermia. (See Appendix K for examples and details.)

An NEDU study (15) found that after an experimental cold-water exposure causing the core temperature to drop to $\sim 35.3^{\circ}\text{C}$, the average change in core temperature due to afterdrop was another 0.5°C down to an average lowest core temperature of 34.8°C (with no subject dropping his core temperature below 34°C). The average amount of time to reach this lowest core temperature due to afterdrop in this study was ~ 10 min. After reaching the lowest "afterdrop" core temperature, the average amount of time to rewarm to a core temperature of $\sim 35.3^{\circ}\text{C}$ using passive rewarming techniques was 30 min.

SUMMARY

Divers today continue to get cold. Specifically, SDV operators and combat swimmers diving in cold water for long durations face a significant thermal challenge. Although only modest improvements have been made to the wet suit and dry suit over the years, a number of manned thermal garment dive studies have yielded some important information. The studies reviewed in this report offer insights into the strengths, weaknesses, and limitations of existing diver thermal garments, as well as insights concerning SDV and combat swimmer mission planning and operations in cold water.

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APPENDIX - A

GENERAL INFORMATION CONCERNING °F & °C

CONVERSION: $(^{\circ}\text{F} - 32) \times 0.56 = ^{\circ}\text{C}$

$(1.79 \times ^{\circ}\text{C}) + 32 = ^{\circ}\text{F}$

TABLE OF CONVERSIONS:

$\frac{^{\circ}\text{F}}{100}$	$\frac{^{\circ}\text{C}}{38}$
98.6	37.2
95	35
90	32
85	29.5
80	26.5
75	24
70	21
65	18.5
60	15.5
55	13
50	10
45	7
40	4.5
35	1.5
30	-1

GENERAL INFORMATION CONCERNING EXERCISE / WORK

Most diving experimental studies utilize a cycle ergometer (underwater stationary bike) in order to exercise their diver-subjects at a known and controlled workload, measured in watts. These are some useful conversions to relate underwater cycling to swimming (note: these are very rough conversions based on a number of variables):

<u>Workload</u>	<u>Cycling work (in watts)</u> <u>(including water resistance)</u>	<u>Swimming speed (in knots)</u>
Rest	0	0
Light-Mod.	30-60	0.5 - 1.0
Mod.-Heavy	60-100	1.0 - 1.3

Note: The average combat swimmer swims at approximately 1 knot.

APPENDIX - B

MEDICAL INFORMATION CONCERNING BODY CORE TEMPERATURES (16)

<u>Degree of Hypothermia</u>	<u>°F</u>	<u>°C</u>	<u>Clinical Findings</u>
None	98.6	37.2	Normal body temperature
None	96.4	36.0	Although not considered a hypothermic temperature, typically people have a cold sensation. Skin is vasoconstricted, they shiver sporadically, have increased muscle tension and an increased metabolic rate, have difficulty concentrating and some short-term memory loss.
Mild	89.6-95	32-35	Typically patients are lethargic and have impaired judgment. They exhibit slow uncoordinated movements, their shivering is greatly increased, and their speech may be slurred or incoherent.
Moderate	82.4-89.6	28-32	Typically these patients are <u>not</u> shivering and have a very low level of consciousness. They are disoriented, confused, and unable to follow commands. There is a risk of fatal cardiac arrhythmias and death.
Severe	<82.4	<28	Typically these patients appear clinically dead with no vital signs, fixed and dilated pupils, and apparent rigor mortis. They exhibit no spontaneous movements, are unresponsive to pain, and have little or no electrical activity on an EKG.

Note: Some sources list the cut-off for "severe" hypothermia at <30 °C (<85.7 °F).

APPENDIX - C

IDENTIFYING DATA

Where published: Undersea and Biomedical Research, Vol. 2, No. 2, June 1975
Title: "Diver Temperature and Performance Changes During Long-duration, Cold Water Exposure"
Author(s): W.S. Vaughan, Jr. (1)

THE STUDY

Subjects (n): 12 men of UDT Team 11
Body fat: (by skin-fold measurement) 12.3% - 15.3%
Diver's Dress: Wet suits - 1/4" Farmer Johns ; 1/8" Vest w/ hood ; 1/4" Jacket w/ hood ; 3/16" Mittens & boots
Location: Puget Sound (Keyport, Washington)
Water Temp: 6°C (43°F)
Duration: Six 4-hour and Four 6-hour SDV training runs
Method: **The divers actually drove/navigated the SDV.** Each "run" had 2 divers (a pilot and a navigator). They completed six 4-hour and four 6-hour (therefore a **total of 20 man-dives**) continuously submerged SDV training runs at 15 fsw depth.

THE RESULTS

Avg start core temp : A. 37.7 °C: 4-hour group; B. 37.6 °C: 6-hour group
Avg finish core temp : A. 36.5 °C: 4-hour group; B. 36.4 °C: 6-hour group
Avg decrease in core temp over the entire exposure: 1.2 °C - for both groups
Range of change in core temp: **between 0.6 °C - 2.1 °C** for the 4-hour group.

Study's conclusions:

"The divers... experienced a state of being more than uncomfortably cold."

"All (divers reported) painfully cold hands and feet ... and involuntary shivering which began during the second hour of each exposure."

"Five of the 12 test divers reported unusual experiences which included periods of double vision and blurry vision, confusion and 'mental driftiness.'"

"...individual differences in (core) temp change were much greater than expected considering the homogeneous insulative characteristics of the divers."

"(Pilot) Heading error consistently increased from $\pm 3.1^\circ$ in the first hour to $\pm 4.7^\circ$ in the fourth, while depth-control error fluctuated between ± 1.5 and ± 2.0 ft."

"These men were made very cold, and yet the main index of deep body cooling - changes in core temperature - did not reflect the severity of the cold stress." "Rather than conclude that the men were not cold in a physiological sense, it is suggested that rectal-intestinal estimates of core temperature are insensitive indices of cold stress above clinically critical values."

REVIEWER'S COMMENTS

Despite a very challenging cold-water exposure, these **acclimatized** (and very motivated) men were able to well-maintain their core body temperature and the heading and depth control of their SDV. The reports of the men's state upon completing their dive, however, leaves open the question of how they might have difficulty performing a more cognitively complex task or a task requiring greater manual dexterity. **Still, 6 h in wet suits in 43 °F water is very impressive.**

APPENDIX - D

IDENTIFYING DATA

Where published: Naval Coastal Systems Lab (NCSL) Report #223-74; Oct 1974
Title: "Gas Consumption of Scuba Divers"
Author(s): M.W. Lippitt, G.F. Bond (2)

THE STUDY

Subjects (n): 5 UDT/SEALs and 1 first-class diver
Body fat: (by skin-fold measurement) 12% - 21%
Diver's Dress: Wet suits - 1/4" Farmer John ; 1/8" Vest w/ hood ; 1/4" Jacket w/ hood ;
3/8" 3-finger Mittens & 1/4" boots
Location: Panama City, FL (NCSL Lab)
Water Temp: 4.5 °C (40 °F), 15.5 °C (60 °F), and 26.5 °C (80 °F)
Duration: 6 h maximum; at 6 fsw maximum.
Method: There were a total of 18 dives - 6 dives at each of the 3 water temps. At each water temp 2 dives were at rest, 2 dives were at light work (swimming at approx. 0.5 knots), and 2 dives were at moderate work (swimming at approx. 0.85 knots).

THE RESULTS

Core temps: Rectal temperatures were monitored with a dive-terminating criteria of 95 °F. None of the divers reached this core temperature. Otherwise, rectal temps were not reported.

Study's conclusions:

All 6 of the dives were completed (reached 6 hours) at the 60 °F water temperature, and 5 of 6 dives were completed at the 80 °F water temp (1 dive was not completed due to equipment problems).

"Only 2 of the 6 divers were able to complete the full 6-hour dives in 40 °F water" (note: 1 of the 2 divers who completed the full 6 hours was at rest while the other was performing "moderate exercise"). The other 4 divers all voluntarily stopped after between 3.5 and 4.0 h for various physical complaints ranging from "cold feet" to a "headache". During the 40 °F water temperature dives, all divers exhibited a "Zombie-like" behavior after leaving the water.

APPENDIX - E

IDENTIFYING DATA

Where published: Naval Coastal Systems Lab (NCSL) Report #271-76; Feb 1976
Title: "Improved Thermal Protection & Rewarm Procedures for cold water dives"
Author(s): M.W. Lippitt, G.F. Bond (3)
Note: LT Ray Smith was the NSW task sponsor

THE STUDY

Subjects (n): 4 UDT/SEALs and 3 first-class divers
Bodyfat: (by skin-fold measurement) 16.1% - 25.4%
Diver's Dress: Wet suits - 1/4" Farmer John ; 1/8" Vest w/ hood ; 1/4" Jacket w/ hood ;
3/8" 3-finger Mittens & 1/4" boots
Dry suits - UNISUIT - variable volume dry suit with "arctic underwear",
with NASA urine collection device (UCD).
Location: Panama City, FL (NCSL Lab)
Water Temp: 1.5 °C (35 °F), 4.5 °C (40 °F), 7.0 °C (45 °F), and 10.0 °C (50 °F)
Duration: 6 h maximum; at 6 fsw maximum.
Method: There were a total of 24 dives under varying conditions of dress, and water temp as listed above. The workload varied between rest, light work (swimming at approx. 0.5 knots), and moderate work (swimming at approx. 0.85 knots).

THE RESULTS

Note: 20 of the dives lasted the full 6 h, while 4 dives were aborted early for various reasons as listed below. The starting and minimum core temps are listed below:

<i>Diver 1/Diver 2</i>	<i>Starting Rectal temp (°F)</i>	<i>Suit/Work</i>	<i>Water (°F)</i>	<i>Minimum rectal Temp Recorded on the dive (°F)</i>
C/E	99.5/99.4	Dry/light	35	97.7/98.5
B/A	99.6/99.0	Dry/mod.	35	98.1/97.4
F/G	100.4/100.5	Dry/rest	35	98.3/98.7
D/E ^{*1}	99.3/99.1	Dry/rest	35	97.9/98.2 ^{*1}
C/A	99.5/99.9	Dry/light	35	97.7/98.4
B/E	99.2/98.8	Dry/light	40	98.1/97.8
F/E ^{*2}	100.4/98.2	Wet/mod.	45	98.3/96.6 ^{*2}
B/A	99.1/98.7	Dry/light	50	98.6/98.0
F ^{*3} /G	99.0/99.2	Wet/light	50	97.8 ^{*3} /98.4
F/G	99.6/99.7	Wet/light	45	98.2/98.3
B ^{*4} /A	99.6/99.0	Wet/mod.	50	97.7 ^{*4} /96.7
C/E	99.0/99.5	Dry/light	45	98.0/98.1
* - reasons for aborts: 1. Gastrointestinal (GI) upset, 2. GI upset, 3. GI upset, 4. Suit collar was too tight and "affected circulation"				

Study's conclusions:

"...almost all of the divers in the dry suit dives had basically stabilized their rectal temps by the end of the third hour."

"At the conclusion of the dives, the men in drysuits were alert and although somewhat fatigued were believed capable of carrying out assigned tasks in a normal manner."

The stabilized rectal temperatures "...together with... the diver's affirmative subjective comments on comfort, strongly support the belief that **the dry suit with urine collection device provided adequate thermal protection for the 35 °F, 6 hour exposures.**"

REVIEWER'S COMMENTS

I question the lack of any performance test to support their claim of divers being able to carry out their assigned tasks in a "normal manner" at the conclusion of these challenging dives. Note the difference in the subjective evaluation of cognitive function between the dry suit dives and the wet suit dives done in this study. The investigators clearly believed that the dives done in dry suits enabled the divers to exit the water after long-duration/cold-water dives in a significantly better cognitive status. The greatest weakness of these subjective observations is that there are no objective measures of performance to support them.

However, looking strictly at the dives completed, **9 out of 10 of the dry suit dives in 35 °F water went the full 6 h (with a lowest rectal temp of 97.4 °F)**. This is very good thermal protection!

APPENDIX - F

IDENTIFYING DATA

Where published: Navy Experimental Diving Unit (NEDU) Report #3-79, Aug 1979
Title: "Manned Evaluation of the NCSC Diver Thermal Protection (DTP) Passive System Prototype"
Author(s): C.A. Piantadosi, D.J. Ball, M.L. Nuckols, E.D. Thalmann (6)

THE STUDY

Subjects (n): 12 first-class divers

Body fat: by skin-fold measurement

Diver's Dress: Dry suits -

1. Outergarment: 2 types were used: one made of a crushed neoprene foam and another made of rubber-coated polyester.
2. Undergarments: "Long-John" underwear and M-400 Thinsulate garment and boots.
3. Gloves: "dry gloves"

Location: NEDU test pool and Ocean Simulation Facility (OSF), Panama City, FL

Water Temp / Depth:

1. Test pool phase: 40 °F / 10 fsw
2. OSF phase: 35 °F / 70 fsw

Duration:

1. Test pool phase: 2.5 h
2. OSF phase: 3 h

Method: A total of 28 manned cold exposures were done, and could be subdivided as follows:

1. The test pool phase (40 °F / 10 fsw / 2.5 h) had a total of 12 manned dives:
 - 4 dives with the divers at rest.
 - 4 dives with the divers performing "moderate work" (doing 50 W of work for 6 min and then 4 min of rest, and repeating this work/rest cycle for the entire dive).
 - 4 dives with the divers performing "heavy work" (doing 50 W of work for 6 min and then 4 min of rest, then doing 100 W of work for 6 min and then 4 min of rest, then doing 150 W of work for 6 min and then 4 min of rest, and repeating this work/rest cycle for the entire dive).
2. The OSF phase (35 °F / 70 fsw / 3 h) had a total of 16 manned dives:
 - 8 dives with the divers at rest.
 - 8 dives with the divers performing "moderate work" (as listed above).

THE RESULTS

Avg start core temp: 1. Test pool phase: rest-37.1 °C; mod. work-37.3 °C; heavy-37.4 °C

2. OSF phase: rest-37.2 °C; mod. work-37.3 °C

Avg finish core temp: 1. Test pool phase: rest-36.6 °C; mod. work-37.2 °C; heavy-36.8 °C

2. OSF phase: rest-36.5 °C; mod. work-37.2 °C

Immersion Aborts: 4 of the 28 manned dives were aborted (2 for significant suit leaks, 1 for "shivering", and 1 for "technical problems").

Study's conclusions:

"Problem areas reported by the dive subjects centered around the outergarment. Difficulty in donning the suit...inadequate neck...and dry glove sealing. Even with dry gloves, most divers reported cold hands and subjectively decreased manual dexterity. Skin temperatures on the dorsal surface of the hand frequently reached 12 °C to 15 °C even during exercise."

"Results indicated that the DTP Passive System Prototype can safely support a working diver for up to 6 hours, and a resting diver for up to 3 hours, in 35-42 °F (1.7-5.6 °C) water. Depth dependent degradation of suit performance was not observed,..."

REVIEWER'S COMMENTS

This study was specifically designed to evaluate the NCSC Diver Thermal Protection (DTP) passive system prototype. **Essentially, this dry suit outergarment, along with M-400 Thinsulate, enabled resting divers to spend 3 h in 35 °C water with an average ending (and lowest) core temperature of 36.5 °C, which is good thermal protection.**

The study also found that **"moderate work" preserved core body temperatures to within 0.1 °C**, given this thermal protection ensemble for up to 3 h in 35-40 °C water. Interestingly, "heavy work" was associated with a greater core temperature drop (0.6 °C) under the same conditions.

The author's conclusion that this thermal protection ensemble could "support a working diver for up to 6 hours" (although perhaps correct) was not tested or proven by this study.

Lastly, again the thermal protection of the hands proved to be very difficult.

APPENDIX - G

IDENTIFYING DATA

Where published: Institute of Naval Medicine (INM) report #25/87; Feb. 1988
Title: "Evaluation of Passive Thermal Protection Systems for cold water diving"
Author(s): E.D. Thalmann, R.B. Schedlich, J.R. Broome, P.E. Barker (4)

THE STUDY

Subjects (n): Royal Marine combat swimmers

Body fat: Not given

Diver's Dress: Wet suits - 4 mm (~1/6") Undershorts; 4 mm (~1/6") Vest w/ hood ;
8 mm (~1/3") Farmer Johns. ; 8 mm (~1/3") Jacket; 6 mm hood
Mittens & boots

Location: INM Alverstoke, Hants, England

Water Temp: 1.4-4.5 °C (35-40 °F)

Duration: Variable (see the Results section)

Method: There were 5 dives in wet suits at rest in 35-40 °F water in the INM test pool at 2-3 meters depth.

THE RESULTS

Avg start core temp : Between 36.5-37.5 °C

Avg finish core temp : Between 36.0-36.5 °C

Avg decrease in core temp : 1.0 °C/h

Study's conclusions:

There were 5 "wet suit runs" (wet suit dives). The mean exposure time for the first four (dives) was 69 min with a standard deviation of 17 min. The last dive was 219 min but the diver was exercising.

"Based on the rectal temperature response, the maximum duration for wet suit runs (in 35-40 °F water) should be 60-90 min. In a swimming diver, with a moderate workload, this duration could probably be doubled."

REVIEWER'S COMMENTS

This study actually evaluated both wet suits and dry suits in 35-40 °F water. The dry suit portion of the study involved more manned dives and is listed separately in this report for reasons of clarity. This portion of the study involved a small number of wet suit dives (only 5 man-dives total). Also, the water temperature varied up to 5 °F. The reason for stopping the dives was also not entirely clear, although the author notes that "...by far the largest single reason for terminating runs was the complaint of cold hands and/or feet."

Therefore, this study concluded that wet suits would support a resting diver for only 60-90 min in 35-40 °F water.

APPENDIX - H

IDENTIFYING DATA

Where published: Institute of Naval Medicine (INM) report #25/87; Feb. 1988
Title: "Evaluation of Passive Thermal Protection Systems for cold water diving"
Author(s): E.D. Thalmann, R.B. Schedlich, J.R. Broome, P.E. Barker (4)

THE STUDY

Subjects (n): Royal Marine combat swimmers

Body fat: Not given

Diver's Dress: Dry suits -

1. Outergarments: Both the Poseidon Unisuit (a foam neoprene dry suit) and the Viking dry suit were tested.
2. Undergarments: The M400/800 Thinsulate and the "Divers Cold water assembly" (DCWA) with and without vest.
3. Gloves: many combinations of gloves were tried (all with limited success).
4. A Urine overboard dump system was utilized.

Location: INM Alverstoke, Hants, England

Water Temp: 1.4-4.5 °C (35-40 °F)

Duration: Variable

Method: There were 20 dives in dry suits at rest in 35-40 °F water in the INM test pool at 2-3 meters depth.

THE RESULTS

Core temps: Rectal temperatures were monitored with a dive-terminating criteria of 35 °C. Rectal temps were reported only in individual graphs for each diver with no summary table or average starting or finishing rectal temps given.

Study's conclusions:

"The issue of duration of exposure was heavily clouded by hand discomfort."

"Exposure times (for the 20 dry suit man-dives) ranged from 46 to 408 min and by far the largest single reason for terminating runs was the complaint of cold hands and/or feet."

APPENDIX - I

IDENTIFYING DATA

Where published: (a) Naval Medical Research Institute (NMRI) report #90-132; Dec 1990.
(b) Unpublished report.

Title: (a) "Coldex-86: Summary of the Experimental Protocol and General Results"
(b) "Coldex-86: Thermal Aspects of Long Term Cold Water Immersion"

Author: (a) T.J. Doubt, R.P. Weinberg, D.J. Smith, P.A. Deuster, A.J. Dutka, E.T. Flynn. (7)
(b) R.P. Weinberg, D.J. Smith, T.J. Doubt, A.J. Dutka. (8)

THE STUDY

Subjects (n): 4 SEALs and 12 first-class divers

Bodyfat: (by skin-fold measurement) 8% - 22% (mean 13%)

Diver's Dress: Dry suits -

1. Outergarment: Butyl rubber with nylon bonded to both sides (Diving Unlimited International)
2. Undergarments: Polypropylene underwear and M600 Thinsulate garment and boots.
3. Gloves: M400 Thinsulate mittens with 5-fingered heavy duty rubber gloves sealed via o-ring to the dry suit. 1/4" neoprene gauntlet mitt was worn over this assembly.
4. A Urine overboard dump system was utilized.

Location: NMRI environmental pool and chamber, Bethesda, MD.

Water Temp: 5 °C (40 °F)

Duration: 6 hours at 20 fsw

Method: Each diver completed 4 cold-water immersions, for a total of 63 man-dives.

Half of the dives involved 9 min of submaximal leg exercise (pedaling the cycle ergometer for 3 min each at workloads of 50, 70, and 90 W; this leg work is similar to swimming at speeds from 0.6-1.5 knots) **every hour on the hour. The other half of the dives performed the same work load, but only during the 3rd and 6th hours of the immersion/dive.**

THE RESULTS

Avg start core temp: 37.45 ± 0.64 °C

Avg core temp after 1 hour: 36.87 ± 0.77 °C

Avg core temp after 2 hour: 36.49 ± 0.72 °C

Avg core temp after 3 hour for the hourly exercise group: 36.37 ± 0.82 °C

Avg core temp after 3 hour for the exercise every 3 h group: 35.96 ± 0.52 °C

Avg core temp after 4 hour: 36.02 ± 0.61 °C

Avg core temp after 5 hour: 36.12 ± 0.66 °C

Avg core temp after 6 hour: 36.06 ± 0.46 °C

Avg net decrease in core temp over the entire 6-hour exposure: 1.9 ± 0.6 °C

Immersion Abort Criteria: An immersion was aborted if:

- the diver's rectal temp dropped 2 °C or reached 35 °C.
- the finger or toe temperature was below 10 °C for 30 min.
- the diver wished to voluntarily stop for any reason.
- there was any equipment malfunction.

Immersion Success Rate: Therefore, of the 63 man-dives/immersions, based on the above abort criteria, the following results were seen:

- 27 dives (43%) went for the full 6-hour duration.
- 5 dives (8%) were terminated due to low rectal temperature.
- 14 dives (22%) were terminated due to low finger/toe temperature.
- 7 dives (11%) were terminated due to the diver voluntarily terminating (5 from gastrointestinal complaints and 2 from headache complaints).
- 10 dives (16%) were terminated due to equipment malfunctions (4 from leaking suit penetrators, 2 from urine spillage, 3 from the rectal temp probe dislodging, and 1 from a flooded facemask).

Study's conclusions:

"Operationally, the probability of successfully completing a 6-hour mission in 5 °C water with this particular suit is likely to be higher than our success rate. The aborts due to research equipment failure would not be encountered in actual diving situations, thereby raising the success rate to about 60%. **Interestingly, only 5 immersions were aborted (out of 63) because of low core temperature. this finding would suggest that the thermal protection provided by the M-600 Thinsulate was adequate to protect core temperature under the present immersion conditions. From another**

viewpoint, a large number of immersions (14 of 63) were aborted because of low finger or toe temperatures, often associated with pain. This is evidence of inadequate thermal protection for the distal extremities, a persistent problem in design of diving suits."

"Thus, from a technical standpoint, the results of this study indicate that 6 hour missions may be accomplished in very cold (5 °C (40 °F)) water with use of a dry suit."

"The effect of hourly exercise (became) significant after 2 hours in maintaining rectal temperatures elevated by an average of nearly 0.5 °C above the group exercising every 3 hours."

"Both finger and toe temperatures... decreased linearly during the first 2 hours to values between 10 and 15 °C. The decrease in digit temperature could be slowed by the diver moving his fingers from an extended position into a fist, presumably reducing the area available for heat loss and increasing blood perfusion."

REVIEWER'S COMMENTS

This study represents a large number of experimental manned dives and therefore carries greater statistical significance than many thermal studies with significantly less man-dives. The author is probably correct in stating that operationally a "success rate" of "60%" (i.e., **that a 6-hour mission may be accomplished in 5 °C (40 °F) water with use of a dry suit 60% of the time**) could be expected. Perhaps the success rate would be even higher given proper time and training in the use of this thermal protection ensemble.

I would also like to echo this study's observation that the **hands and feet continue to be the weakest link in the diver's thermal protection ensemble**.

Finally, the effect of hourly exercise for only 9 min/h is noteworthy. Exercise kept this group of divers significantly warmer than the "non-exercising" group.

APPENDIX - J

IDENTIFYING DATA

Where published: Naval Medical Research Institute (NMRI) report #90-52; June 1990
Title: "Effects of Hand and Foot Heating on Diver Thermal Balance"
Author(s): R.P. Weinberg, E.D. Thalmann (9)

THE STUDY

Subjects (n): 32 U.S. Navy divers

Bodyfat: Not reported

Diver's Dress: Dry suits -

1. Outergarment: TLS (Trilaminate-butyl nylon) by Diving Unlimited International.
2. Undergarments: Polypropylene underwear and M-400 Thinsulate in the knees, seat, shoulders, and elbows; and M-600 in the calves, thighs, arms, and forearms; M-800 in the trunk.
3. Hood: M-400 Thinsulate hood underneath a 1/4" foam neoprene wet suit hood.
4. A Urine overboard dump system was utilized.
5. Gloves: See methods section.

Note: The divers wore **40 kg (88 lb) of weight** to provide slight negative buoyancy given the above dress.

Location: NMRI immersion tank, Bethesda, MD.

Water Temp: 3 °C (37 °F)

Duration: 8 h

Method: There were a total of 37 manned immersions/dives, all done at rest, that could be subdivided according to the type of supplemental hand & foot heating provided as follows:

- Series 1: - 5 immersions with **passive hand heating only** consisting of a polypropylene liner, 1/8" foam neoprene five-fingered outer glove.
 - 8 immersions with the same passive glove protection and with **warm-water perfused gloves** and socks with supplemental heating sufficient to maintain **12 °C** digit temperatures.
 - 8 immersions with the same passive glove protection and with **warm-water perfused gloves** and socks with supplemental heating sufficient to maintain **18 °C** digit temperatures.
- Series 2: - 8 immersions with passive hand heating consisting of a polypropylene liner, M-200 Thinsulate five-fingered gloves and a latex outer glove and an **electrically heated glove** providing

constant heating.

- 8 immersions with the same passive glove protection and the **same electrically heated gloves** but providing **intermittent** heating to maintain **18 °C** digit temperatures.

THE RESULTS

Avg start core temp : Between 37.3 and 37.5 °C

Avg finish core temp : Between 36.0 and 36.1 °C

Avg decrease in core temp : 1.2 °C \pm 0.3 in 8 h

Study's conclusions:

"A total of 29 successful immersions (out of 37 attempts) were made in the 3 experimental series. Of the unsuccessful attempts, 5 were due to equipment failure (leaks, lack of safety temperature readouts, and catheter not working), and 3 were due to subject requests (cold feet, cold hands, headache)."

"The failure rate observed for all series was essentially due to research equipment problems; only one instance of a suit leak occurred. Requests for abort by the diver occurred primarily during unheated and 12 °C digit temp immersions. The only instance of abort at 18 °C digit heating was due to headache."

"The dry suit worn in this study adequately protected resting diver core temperature as rectal temperature did not drop below 36 °C after 8 hours of immersion in 3 °C water."

"Rectal temps decreased in both heated and unheated divers during the first 3 hours of immersion from 37.4 ± 0.2 °C to 36.2 ± 0.2 °C and remained steady for the rest of the immersion independent of supplemental heating levels."

"The effect of supplemental heating of the hands and feet did not appear to influence (the) overall total body net thermal balance."

"Supplemental heating of digits to 12 °C was not satisfactory based on diver subjective evaluation. Greater thermal discomfort was reported by the divers at 12 °C versus 18 °C digit temps, but both levels of digit heating were judged to be more comfortable than the unheated condition. However, there was no measurable difference in hand grip strength or manual dexterity between the two levels of supplemental heating."

"Divers with unheated digits were significantly different from the heated groups when measured at 2 hours of immersion, and were unable to complete the (manual dexterity) test at subsequent test intervals due to finger numbness."

"If digit temps of 18 °C are maintained, the 50-watt power supply (necessary to run the electrically heated gloves that proved to be more energy efficient than the warm-water perfused gloves) is small enough that a diver could probably carry a 6- to 8-hour power supply with him."

REVIEWER'S COMMENTS

This study essentially picked up where the Thalmann INM study of 1987 (4) left off. In that study, Thalmann demonstrated that given the right thermal protection (an M-600 Thinsulate undergarment and dry suit outergarment), 6- to 7-hour dives at rest in ~3 °C water could be accomplished with only an ~1.0 °C drop in core body temperature. The greatest problem in that and in other studies was adequate thermal protection of the extremities. **Therefore, this study sought to eliminate extremity temperatures as the "mission-limiting factor" by utilizing active thermal heating for the hands and feet only.**

The results are impressive. First, the dry suit ensemble did protect the resting diver's core temperature (as rectal temperature did not drop below 36 °C after 8 h of immersion in 3 °C water). **The electric gloves using 50 W of power** (a power source about the size of 1/2 of a car battery) **did maintain the digits at 18 °C, thereby preserving diver hand and foot comfort, and manual dexterity** (although grip strength still declined, probably because the forearm muscles primarily determine grip strength and were not benefited by the supplemental hand heating). **Another very important observation was that the effect of supplemental heating of the hands and feet did not appear to influence overall total body net thermal balance.**

APPENDIX - K

IDENTIFYING DATA

Where published: Naval Health Research Center (NHRC) Report No. 93-27
Title: "Thermal and Physiological Responses of Basic Underwater Demolition/SEAL (BUD/S) Students to a 5.5-mile Open-ocean Swim"
Author: W.K. Prusaczyk, H.W. Goforth Jr., T. Sopchick, P. Griffith, K. Schneider (5)

THE STUDY

Subjects (n): 60 BUD/S Students

Bodyfat: (by skin-fold measurement) 6.6%

Diver's Dress:

1. December 1991 group: "Full body wet suit" (9.5 mm (3/8")) with hood & booties (fins & mask)
2. April 1992 group: "Wet suit top" (9.5 mm (3/8")) with hood & booties (fins & mask)

Location: Coronado, Ca.

Water Temp:

1. December 1991 group: 13 °C (57 °F)
2. April 1992 group: 16.7 °C (62 °F)

Duration:

1. December 1991 group: 240.7 (± 23.6) min
2. April 1992 group: 232.8 (± 12.6) min

Method: 1. 36 BUD/S students wearing a "full body wet suit" in December 1991 surface swam 5.5 miles with a mean swim time of 240.7 minutes in 13 °C (57 °F) water.

2. 24 BUD/S students wearing a "wet suit top" in April 1992 surface swam 5.5 miles with a mean swim time of 232.8 min in 16.7 °C (62 °F) water.

THE RESULTS

Avg start core temp :

1. December 1991 group: 100.1 - 98.3 °F with a mean of 99.2 °F
2. April 1992 group: 99.2 - 98.4 °F with a mean of 99.2 °F

Avg finish core temp :

1. December 1991 group: 100.0 - 94.9 °F with a mean of 98.1 °F
2. April 1992 group: 98.9 - 93.0 °F with a mean of 96.6 °F

Avg decrease in core temp over the entire exposure: 1. December 1991 group: 0.6 °C
(1.1 °F)
2. April 1992 group: 1.4 °C
(1.8 °F)

Study's conclusions:

In the December 1991 group "one student (2.7% of December swimmers) exhibited a hypothermic temperature (34.9 °C (94.9 °F))", while in the April 1992 group "three students (12.5% of April swimmers) exhibited hypothermic core body temperatures" (with the lowest temp being 34.1 °C (93.0 °F)).

"Despite the warmer water temperatures in April, students had greater core temperature drops and greater drop rates than in December."

" The difference in core temperature response is likely due to the thermal protection on the swimmers' legs; wet suit top in April compared to full body wet suit in December. In December, the active musculature of the legs was covered, effectively reducing the body-to-water thermal gradient resulting in greater body heat conservation."

REVIEWER'S COMMENTS

This study highlights the necessity to cover the exercising muscle groups (i.e., the thighs/legs) while swimming in order to maximize thermal protection.

Despite the warmer water temperature, the April BUD/S class had greater core temperature drops than the BUD/S class that swam in the colder December water. The difference: the April class only wore wet suit tops (while the December class wore a full body wet suit) and probably had greater heat loss through the exercising muscle groups (the legs).

The average time delay between when the swimmer exited the water and when his post-swim core body temperature was measured was 13.4 min. Therefore, the effect of "afterdrop" is probably reflected in this post-swim measurement. The authors of this study point out however, that this post-swim temperature measurement accurately reflects the true thermal status shortly after water exit. This is a time when an NSW operator may be beginning the land phase of his mission after a water-borne/swimming insertion.

Body core afterdrop is defined as the continual decline in body core temperature during the initial rewarming period. The afterdrop effect is due to the return of cooled blood from the extremities to the central or core circulation as the diver begins to rewarm after a cold exposure. An NEDU study (15) found that after an experimental cold-water exposure causing the core temperature to drop to $\sim 35.3^{\circ}\text{C}$, the average change in core temperature due to afterdrop was another 0.5°C down to an average lowest core temperature of 34.8°C (with no subject dropping his core temperature below 34°C). The average amount of time to reach this lowest core temperature due to afterdrop in this study was ~ 10 min. After reaching the lowest “afterdrop” core temperature, the average amount of time to rewarm to a core temperature of $\sim 35.3^{\circ}\text{C}$ using passive rewarming techniques was 30 min.

The afterdrop effect is a normal and predictable physiological mechanism. It must be kept in mind by SDV operators and combat swimmers who plan a land phase to their mission. During their initial transition to the typically warmer land phase, the core temperature will probably reach its lowest point, and the diver may be most vulnerable to the effects of even mild hypothermia.

APPENDIX - L

IDENTIFYING DATA

Where published: Naval Medical Research Institute (NMRI) report #89-35; Mar 1989
Title: "Effects of Serial Wet-Dry-Wet Exposure: Thermal Balance, Physical Activity, and Cognitive Performance"
Author: T.J. Doubt, R.P. Weinberg, R.L. Hesslink, S.T. Ahlers (10)

THE STUDY

Subjects (n): 7 U.S. Navy first-class divers

Body fat: (by skin-fold measurement) 7.9% - 20.0% (mean 14.3%)

Diver's Dress: Dry suits -

1. Outergarment: Tri-laminated dry suit (TLS by Diving Unlimited International)
2. Undergarments: Polypropylene underwear and M400 Thinsulate garment and boots.
3. Gloves: wool gloves worn beneath M200 Thinsulate gloves with 5-fingered electrician's rubber gloves sealed via o-ring to the dry suit. 6 mm neoprene gauntlet mitt was worn over this assembly.
4. A Urine overboard dump system was utilized.

Location: NMRI environmental pool and chamber, Bethesda, MD.

Water and Air Temps: both the water and air temps were kept at 5 °C (40 °F)

Duration: 7 h total cold exposure time.

Method: Each subject went through two exposures (one where he exercised during the dry phase and one where he was at rest during the dry phase) for a total of 14 manned cold exposures. Each exposure was divided into 3 phases:

phase 1 - a 2.5-hour dive in 5 °C water (to simulate an insertion). The diver was at rest for the first 2 h and then performed light leg exercise (workload of 50 W; simulating the work effort required to swim/exit the water) for the last 30 min.

phase 2 - a 2-hour dry cold exposure at 5 °C air temp. The 2-hour dry cold exposure involved either walking on a treadmill at a slow pace (to simulate an active diver on land) or sitting quietly at rest (to simulate an inactive diver).

phase 3 - a 2.5-hour dive in 5 °C water (to simulate an extraction). The diver again performed light leg exercise for the first 30 min to simulate return to the water and then was at rest for the last 2 h (simulating a return transit).

"...6 of (the) 14 (manned dives/exposures) tests were terminated prematurely (4 of the 6 were aborted early because of dry suit leaks)."

REVIEWER'S COMMENTS

This study was patterned after a February 1987 NSW training exercise that involved a serial wet-dry-wet exposure in similar water and air temps and of similar duration. The observation was made on that exercise that "vigilance... appeared to be reduced" and that "procedural errors were made when the divers prepared to reenter the water". Therefore, the question of the role (if any) hypothermia and/or fatigue played in these decrements in performance was asked. The answers the study provides are not surprising, but do serve to objectively quantify some of the physiological measures probably found on many similar NSW missions/exercises:

- The **dry suit and thinsulate undergarments did preserve the core body temperature above hypothermic levels** when used under the exposure conditions found in this study (a 2.5-hour dive in 5 °C water, followed by a 2-hour dry cold exposure at 5 °C air temperature, and lastly another 2.5-hour dive in 5 °C water). **It should be noted, however, that while core temperature may be preserved, this does not preclude shivering and/or decrements in performance due to the stresses of a cold exposure** (also seen in this study).

- The **hands** became painfully cold (skin temps around 11 °C) by approximately 2 h into the exposure and represent, in all likelihood, **the weakest link in the thermal protection ensemble**.

- The **beneficial effect of even light leg exercise** in keeping core and extremity temperatures elevated was not surprising, but the degree of this benefit was somewhat surprising. **This was truly light exercise (walking on a treadmill at a slow pace) of the legs only, but it significantly affected both the core and hand/extremity temperatures**. Therefore, the thermal benefits of even light exercise should not be underestimated.

- The loss of more than 2 kg (4.4 lb) of body weight and 12-13% of plasma volume (moderate dehydration) is noteworthy, as even mild dehydration can negatively affect performance.

- **Dehydration is a major factor affecting performance and a real problem in prolonged cold water diving**. Underwater a person is in a state of near weightlessness. Without the pull of gravity, more blood ends up in the central circulation. The heart, in turn, has certain "sensors" that incorrectly interpret this

increased blood flow as an increase in overall blood volume. The heart then releases a hormone that causes the kidneys to start to dump fluid (urate). This problem is only compounded by cold water, which causes the extremities to vasoconstrict, causing even more blood to find its way into the central circulation. The end result is inevitably a dehydrated diver. This means that a diver's heart will have to work significantly harder to get blood to exercising muscles. **Therefore, the amount of work he is able to perform would be below normal.**

- Perhaps the performance decrements seen in this study were due to multiple factors including cold stress, dehydration, and generalized fatigue.

"These results show that cold-water acclimation can be achieved in a laboratory setting and that acclimation, with regard to SkBF responses, is complete within 2 weeks."

REVIEWER'S COMMENTS

Acclimatization to cold has been reported in groups chronically exposed to cold without thermal protective garments. This investigation tested the hypothesis that cold acclimation can be induced in a laboratory setting and observed the time course of that acclimation.

Measures of skin blood flow are important, as the ability of the skin to vasoconstrict (limit the blood flow to the skin) is one of the key mechanisms to preserving core body temperature. Vasoconstriction limits heat loss and improves the insulation of the body. Therefore, the finding that skin blood flow was maximally decreased after 2 weeks of daily exposures in 64 °F water is important for two reasons: 1) it only takes 2 weeks to become acclimated (many experts before this study would probably have recommended much longer) and 2) longer time courses of exposures (4 or 6 weeks) do not improve the degree of acclimation.

Therefore, the SDV operator or combat swimmer who anticipates a cold-water mission or exercise should (if time permits) acclimate his divers by taking daily swims in 64 °F water for 1.5 h daily for 2 weeks. This improved acclimation should persist for another 2 weeks (noted in personal communication with W.F. Taylor).